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(54) **FAST-ACCESS SELF-REPAIRING TAPE LIBRARY USING MOBILE ROBOTS**

(71) Applicant: **International Business Machines Corporation**, Armonk, NY (US)

(72) Inventor: **Gary M. McClelland**, Palo Alto, CA (US)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,715,040 A	2/1973	Polus	
4,432,508 A *	2/1984	Inoue	G11B 15/67
			226/92
4,864,511 A	9/1989	Moy et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0558252	1/1993
JP	S5933660 A	2/1984

(Continued)

OTHER PUBLICATIONS

Hanaoka et al., "Technologies for Realizing New Eternus LT270 High-End Tape Library System," FUJITSU Sci. Tech. J., vol. 42, No. 1, Jan. 2006, pp. 24-31.
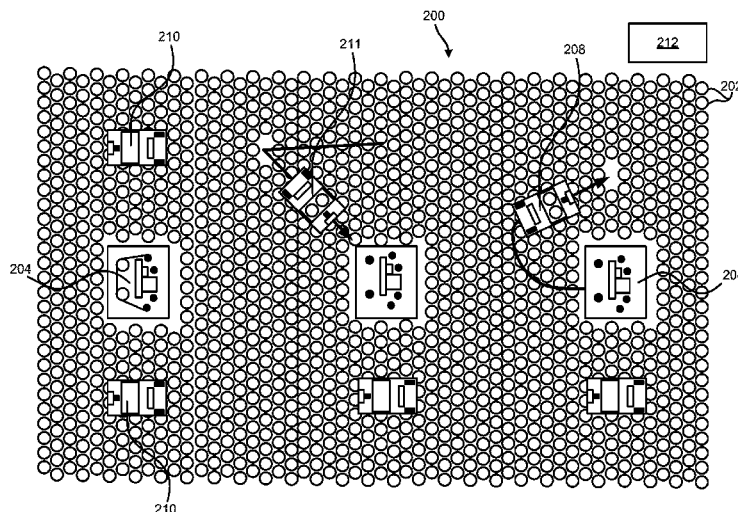
(Continued)

Primary Examiner — Kyle Logan
(74) *Attorney, Agent, or Firm* — Zilka-Kotab, PC

(57) **ABSTRACT**

Various methods for threading a tape on the one or more reels onto the tape drive. A method according to one embodiment uses a mobile robot to thread a tape on the one or more reels onto the tape drive. A method according to another embodiment includes threading a tape across a tape drive by moving at least one of a tape reel and a take up reel coupled to the tape. A method according to yet another embodiment includes threading the tape across a tape drive using at least one of rollers and cylinders.

18 Claims, 10 Drawing Sheets

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,928,245 A	5/1990	Moy et al.	
4,932,826 A	6/1990	Moy et al.	
4,989,191 A	1/1991	Kuo	
5,081,548 A	1/1992	Inazawa et al.	
5,150,452 A *	9/1992	Pollack et al.	700/255
5,155,639 A *	10/1992	Platter	G11B 15/607
			242/332.4
5,214,768 A	5/1993	Martin et al.	
5,333,810 A *	8/1994	Hoge	G11B 15/67
			242/332.4
5,367,410 A	11/1994	McCarthy	
5,395,199 A	3/1995	Day, III et al.	
5,412,791 A	5/1995	Martin et al.	
5,504,873 A	4/1996	Martin et al.	
5,557,770 A	9/1996	Bhide et al.	
5,906,324 A *	5/1999	Adams	G03B 1/58
			242/332.8
5,956,301 A	9/1999	Dimitri et al.	
6,198,593 B1	3/2001	Hori et al.	
6,260,006 B1	7/2001	Wong et al.	
6,421,579 B1	7/2002	Dimitri et al.	
6,438,459 B1	8/2002	Dimitri et al.	
6,718,228 B2	4/2004	Campbell et al.	
6,808,353 B2	10/2004	Ostwald et al.	
6,856,985 B1 *	2/2005	Pierce et al.	
6,868,049 B2	3/2005	Ostwald et al.	
7,039,657 B1	5/2006	Bish et al.	
7,546,180 B1 *	6/2009	Ries et al.	700/248
8,019,455 B2 *	9/2011	Maenishi et al.	700/99
8,065,033 B2 *	11/2011	Hoshino	700/218
8,108,065 B2 *	1/2012	Greco et al.	700/214
8,159,776 B2	4/2012	Fujita et al.	
8,198,593 B2	6/2012	Kito et al.	
8,244,403 B2 *	8/2012	Lin et al.	700/253
8,494,674 B2	7/2013	McClelland	
8,509,946 B2	8/2013	McClelland	
8,666,535 B2	3/2014	McClelland	
8,862,265 B2 *	10/2014	McClelland	700/218
9,263,082 B2	2/2016	Hetzler et al.	
2002/0062167 A1 *	5/2002	Dimitri et al.	700/214
2002/0087783 A1	7/2002	Leonhardt et al.	
2003/0016465 A1 *	1/2003	Bui	G11B 5/584
			360/72.3
2003/0063966 A1	4/2003	Apple et al.	
2004/0149850 A1 *	8/2004	Nejezchleb	G11B 23/107
			242/348
2005/0256999 A1	11/2005	Kishi et al.	
2007/0266203 A1	11/2007	Amano et al.	
2008/0201012 A1	8/2008	Hoshino	
2009/0177314 A1 *	7/2009	Greco et al.	700/218
2010/0030378 A1	2/2010	Choi et al.	
2010/0042247 A1	2/2010	Starr et al.	
2011/0122527 A1	5/2011	Amir et al.	
2011/0213493 A1 *	9/2011	Stutz	700/218
2011/0292531 A1	12/2011	Sato	
2012/0110257 A1	5/2012	Enohara et al.	
2012/0148379 A1	6/2012	Green et al.	
2012/0287532 A1	11/2012	Acevedo et al.	
2013/0054006 A1	2/2013	McClelland	
2013/0054007 A1	2/2013	McClelland	
2013/0226333 A1	8/2013	McClelland	
2013/0245813 A1	9/2013	McClelland	
2014/0211602 A1	7/2014	Hetzler	
2016/0005432 A1	1/2016	Hetzler et al.	

FOREIGN PATENT DOCUMENTS

JP	H04302846 A	10/1992
JP	0684251	3/1994
JP	2002373464 A	12/2002
JP	2004-086251	3/2004
WO	0041093 A2	7/2000

OTHER PUBLICATIONS

"Classification Definitions," Dec. 2000, pp. 901/1-901/18.

Johnson, C., "IBM 3850—Mass storage system," AFIPS '75 Proceedings of the May 19-22, 1975, national computer conference and exposition, pp. 509-514.

Dean et al., "Multi-Arm Journaling," IBM TDB, IPCOM000119590D, Feb. 1, 1991, vol. 33, No. 9, pp. 107-111.

"Systems: Introduction to the IBM 3850 Mass Storage System (MSS)," IBM, Third Edition, Jul. 1975, pp. 1-92.

"IBM 3850," Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/IBM_3850, last modified Oct. 31, 2012, downloaded Jan. 29, 2013.

Non-Final Office Action from U.S. Appl. No. 13/217,181 dated Oct. 5, 2012.

Notice of Allowance and Fee(s) Due from U.S. Appl. No. 13/217,181 dated Mar. 26, 2013.

Non-Final Office Action from U.S. Appl. No. 13/558,232 dated Oct. 3, 2012.

Notice of Allowance and Fee(s) Due from U.S. Appl. No. 13/558,232 dated Apr. 8, 2013.

U.S. Appl. No. 13/859,668, filed Apr. 9, 2013.

Non-Final Office Action from U.S. Appl. No. 13/859,668 dated Jun. 20, 2013.

Notice of Allowance and Fee(s) Due from U.S. Appl. No. 13/859,668 dated Oct. 16, 2013.

U.S. Appl. No. 13/888,287, filed on May 6, 2013.

Non-Final Office Action from U.S. Appl. No. 13/888,287 dated Aug. 19, 2013.

Final Office Action from U.S. Appl. No. 13/888,287 dated Mar. 3, 2014

Notice of Allowance and Fee(s) Due from U.S. Appl. No. 13/888,287 dated Jun. 6, 2014.

U.S. Appl. No. 13/754,714, filed Jan. 30, 2013.

U.S. Appl. No. 13/217,181, filed Aug. 24, 2011.

U.S. Appl. No. 13/558,232, filed, Jul. 25, 2012.

International Search Report and Written Opinion from PCT Application No. PCT/IB2014/058593 dated May 13, 2014.

Notice of Allowance from U.S. Appl. No. 13/754,714, dated Sep. 16, 2015.

Non-Final Office Action from U.S. Appl. No. 13/754,714, dated Nov. 7, 2014.

Final Office Action from U.S. Appl. No. 13/754,714, dated Mar. 12, 2015.

Non-Final Office Action from U.S. Appl. No. 13/754,714, dated Mar. 23, 2015.

Final Office Action from U.S. Appl. No. 13/754,714, dated Jul. 16, 2015.

Hetzler et al., U.S. Appl. No. 14/855,294, filed Sep. 15, 2015.
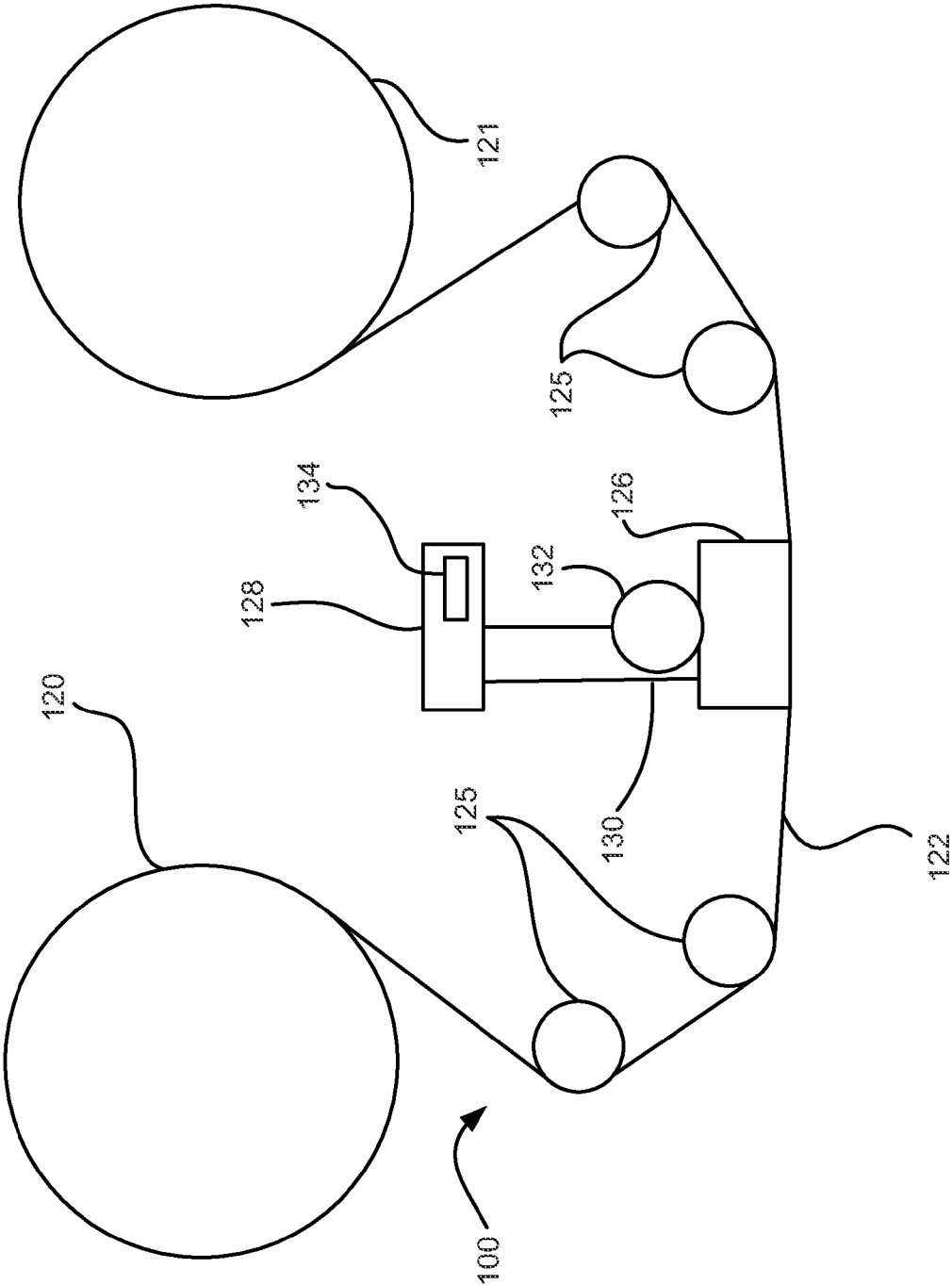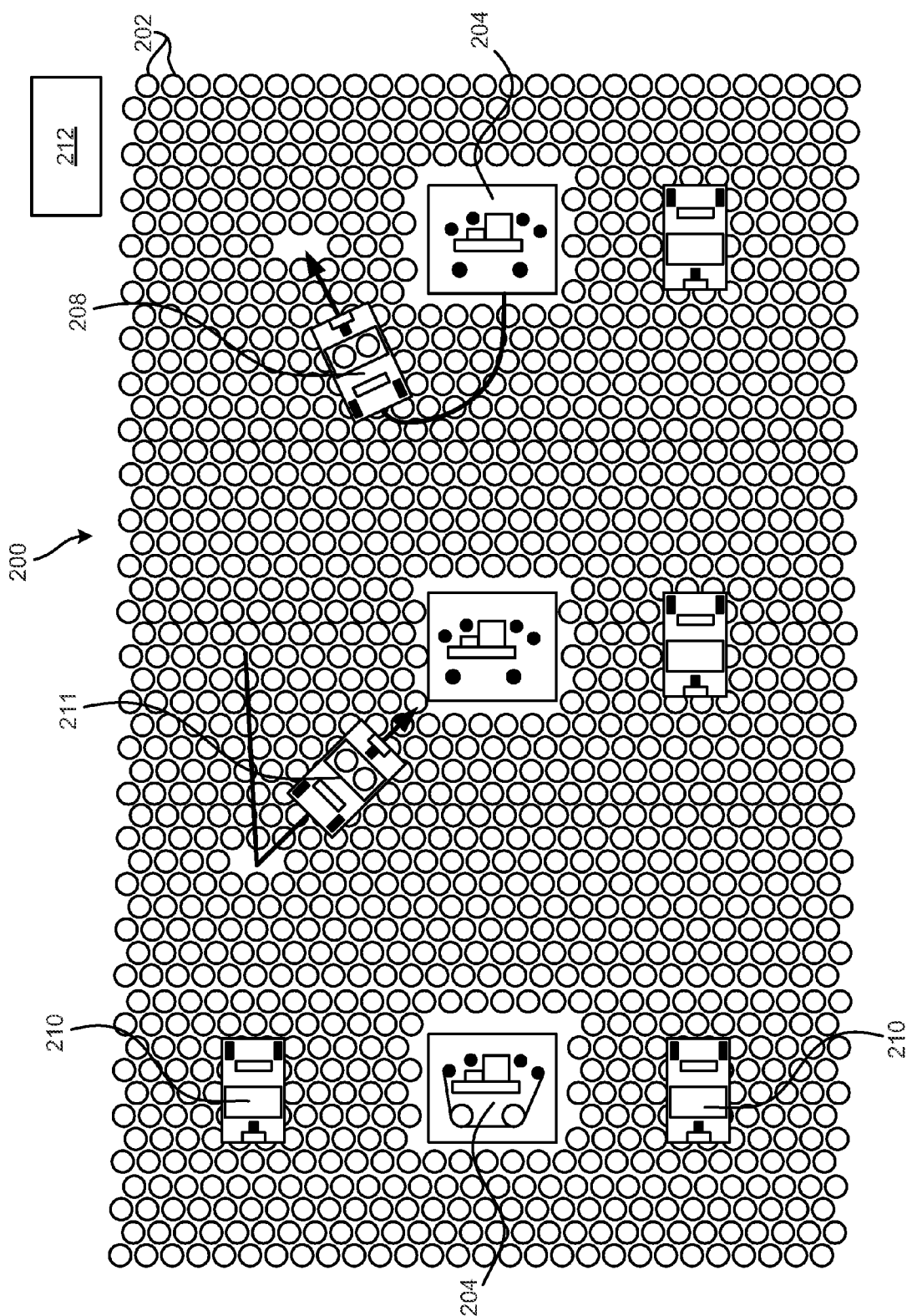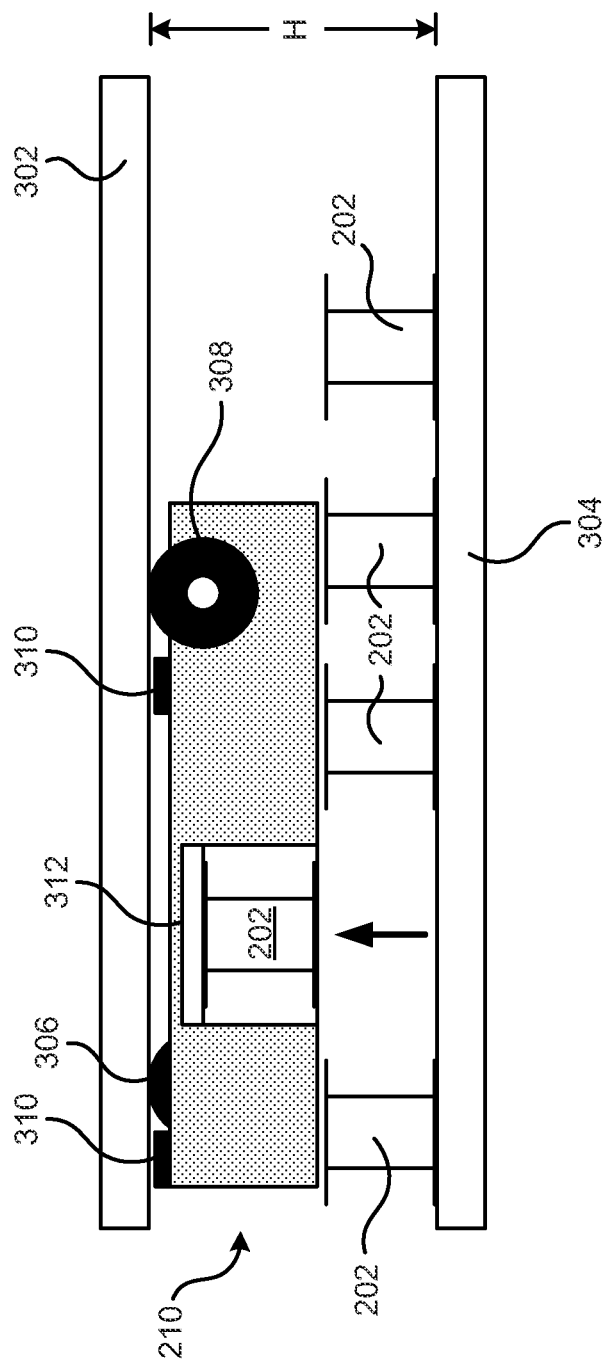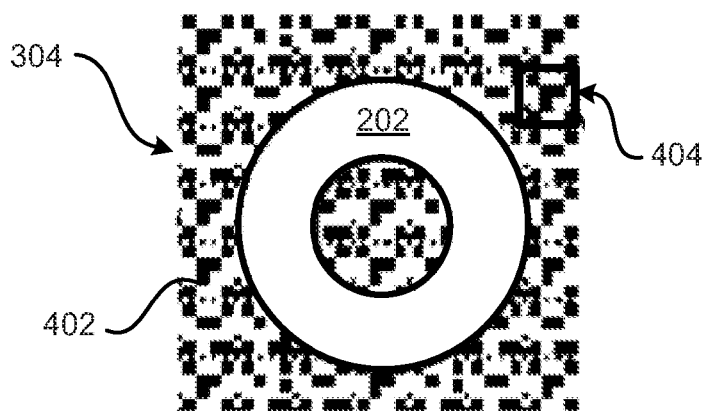
* cited by examiner

FIG. 1

FIG. 2

FIG. 3

304

202

404

402

FIG. 4A

202   202   202

304

FIG. 4B

202   202   202

304

FIG. 4C

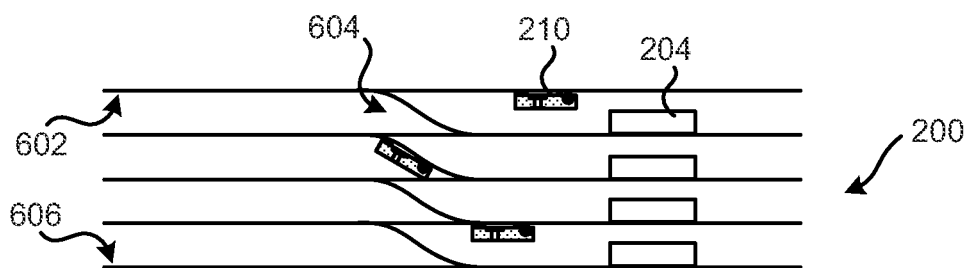202   202   202   304
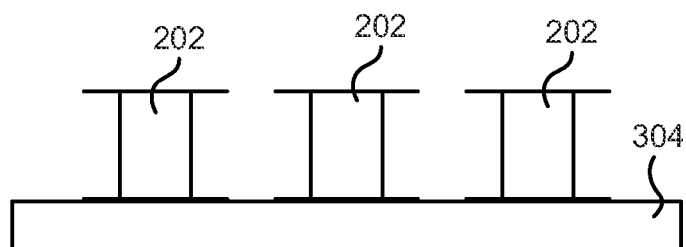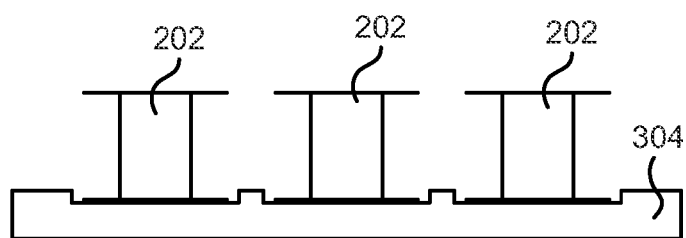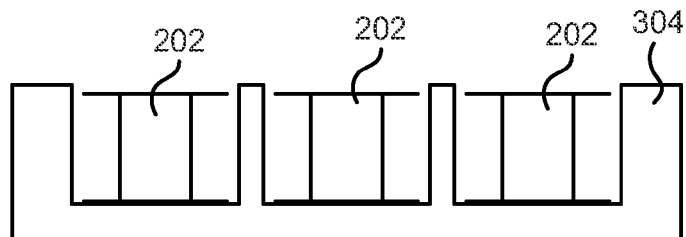
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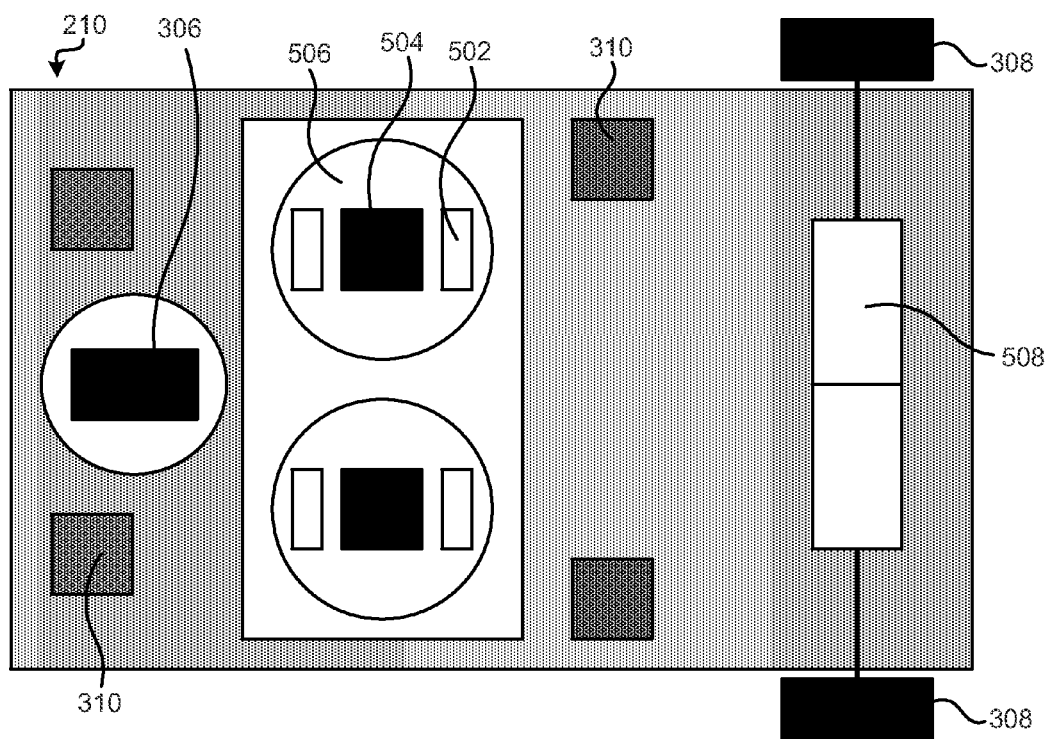
FIG. 5A
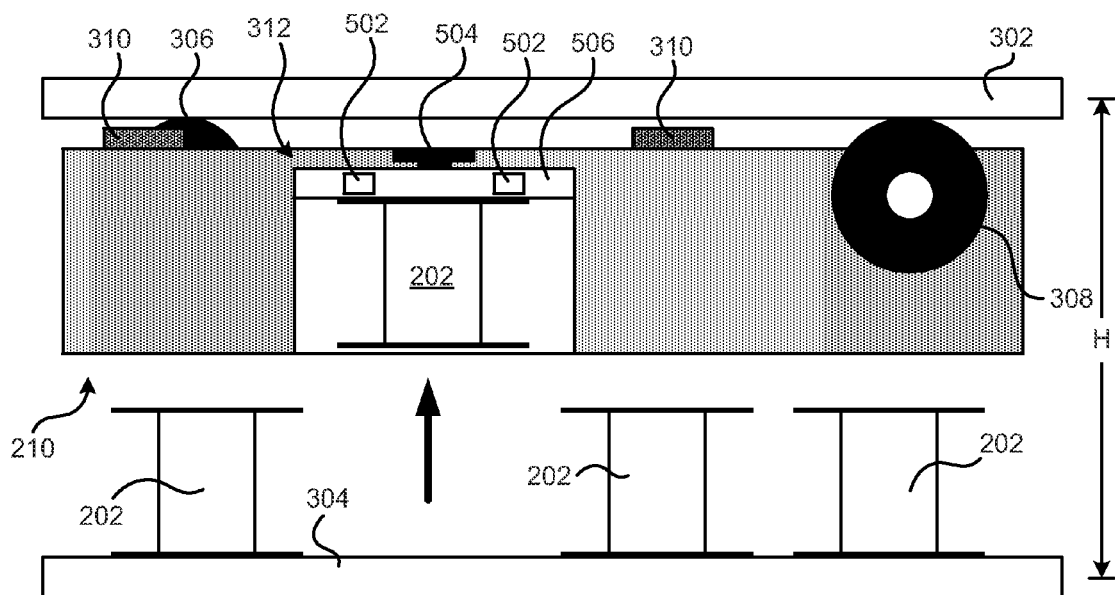
FIG. 5B
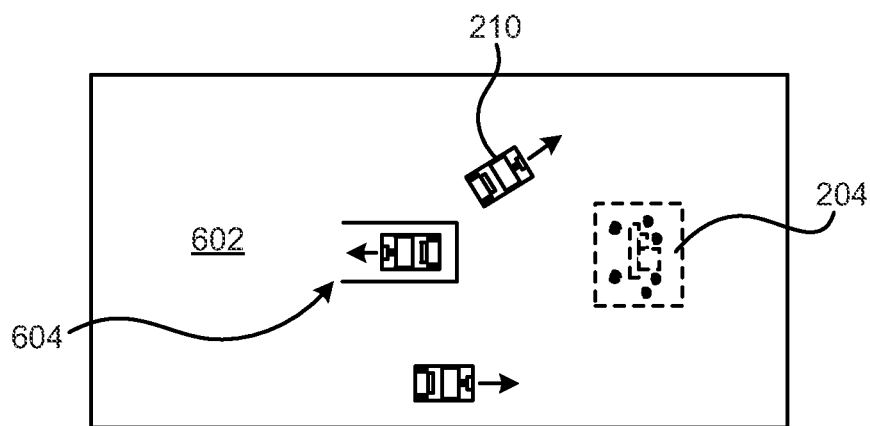
FIG. 6A

FIG. 6B
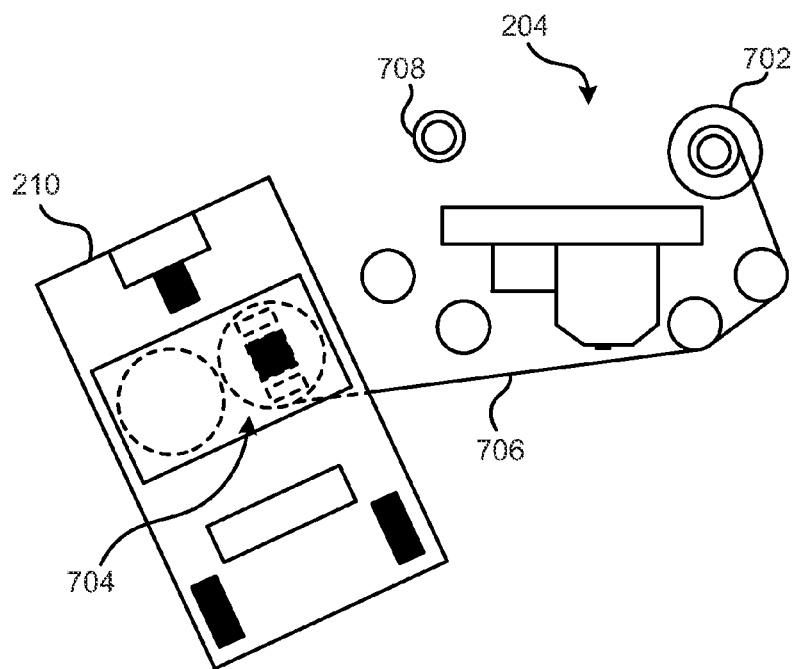
FIG. 7A
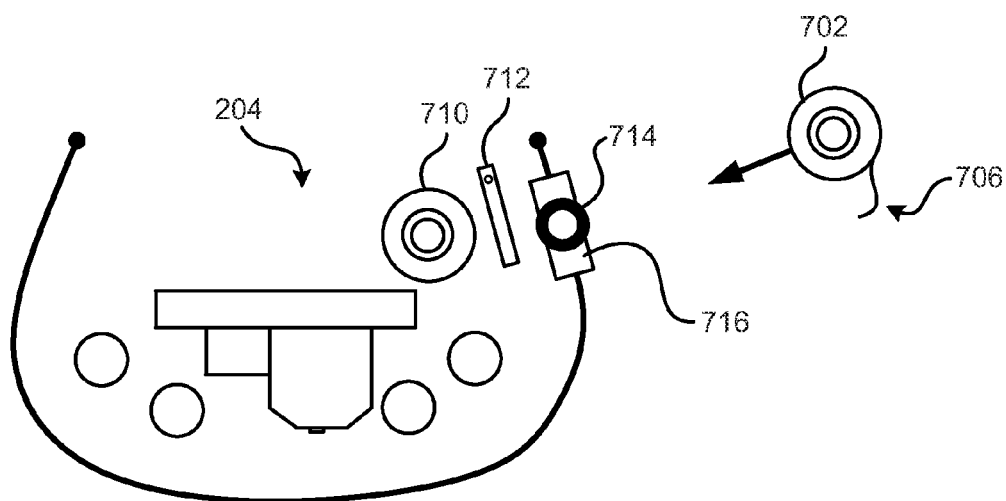
FIG. 7B
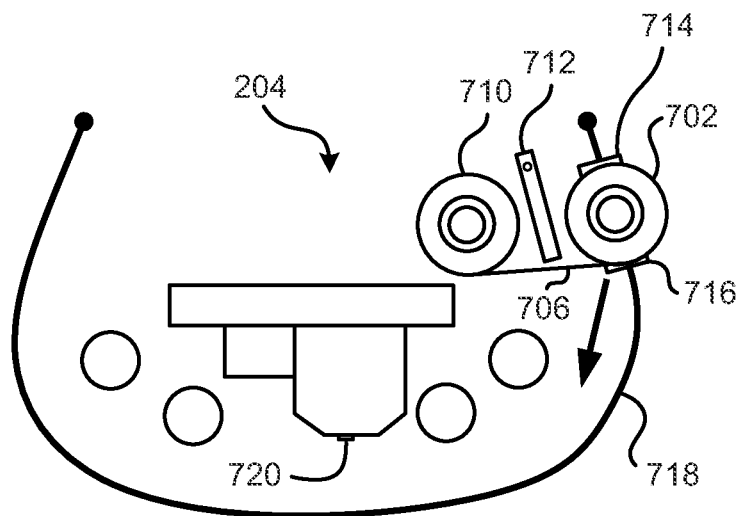
FIG. 7C
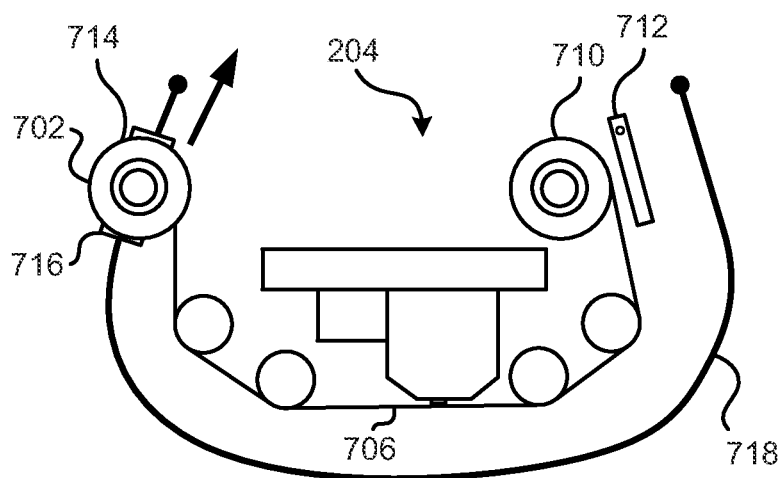
FIG. 7D
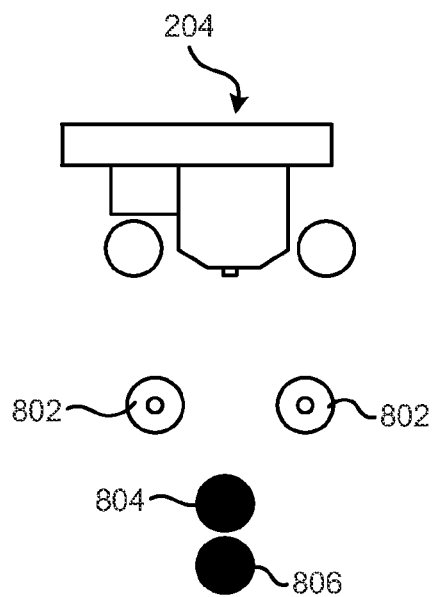
FIG. 8A
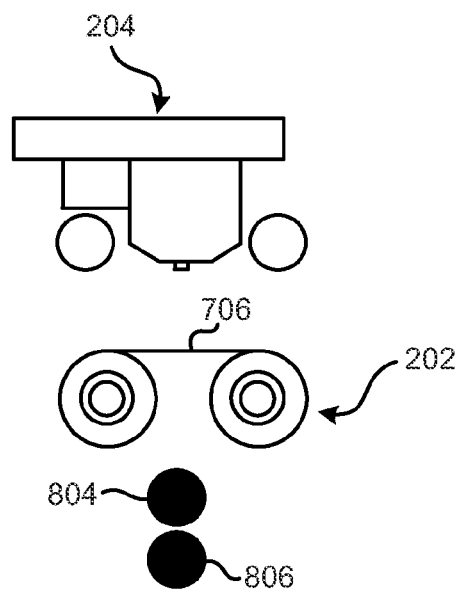
FIG. 8B
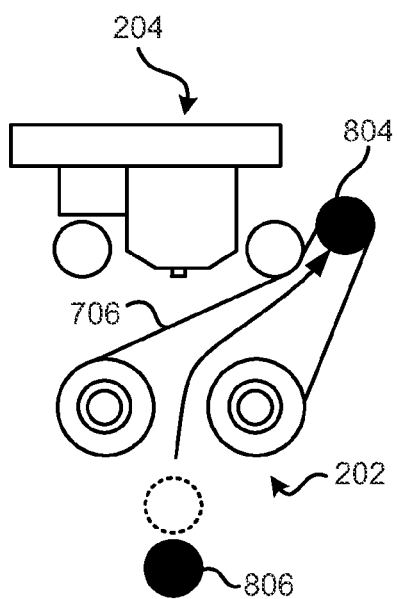
FIG. 8C

FIG. 8D

202

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FIG. 9A

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FIG. 9B

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904

202

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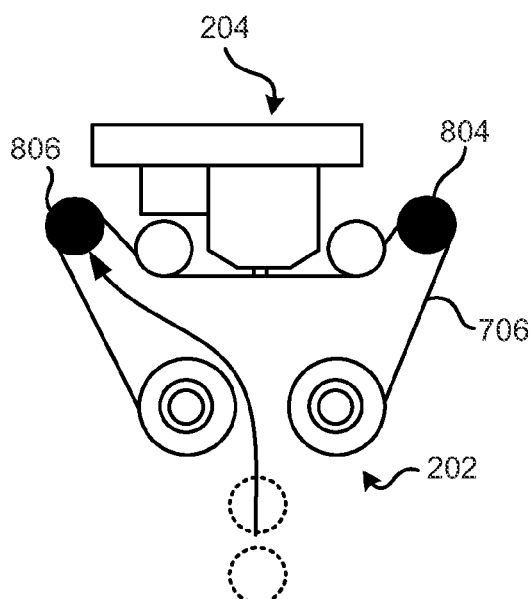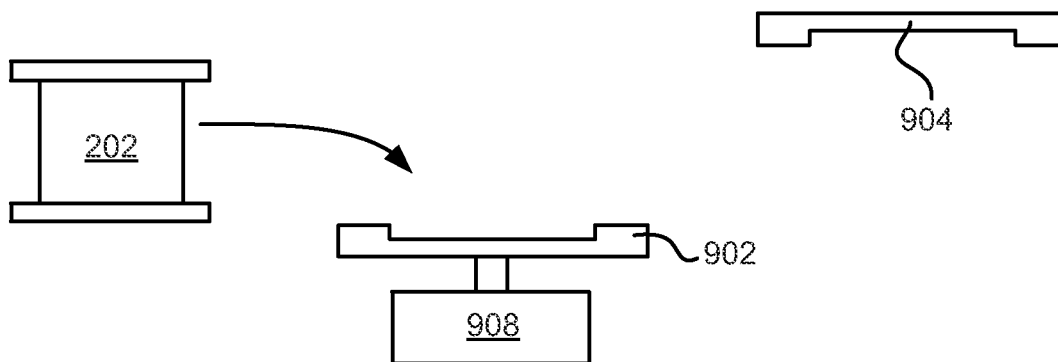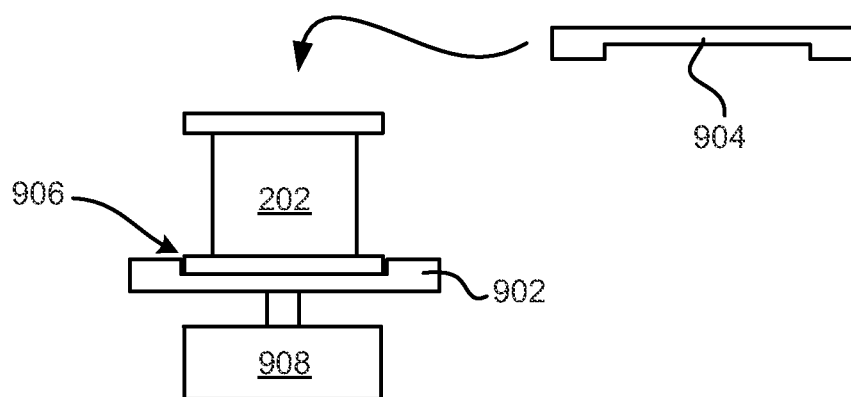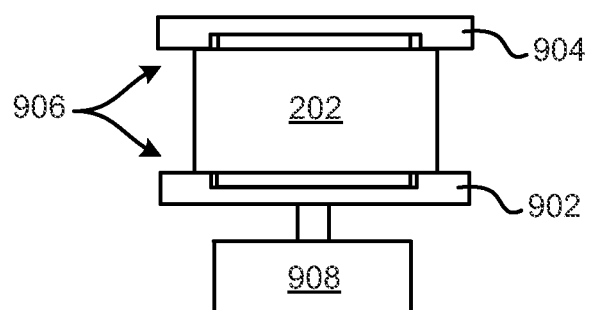
FIG. 9C

FAST-ACCESS SELF-REPAIRING TAPE LIBRARY USING MOBILE ROBOTS

RELATED APPLICATIONS

This application is a continuation of copending U.S. patent application Ser. No. 13/888,287 filed May 6, 2013, which is a continuation of U.S. patent application Ser. No. 13/558,232 filed Jul. 25, 2012, which is a continuation of U.S. patent application Ser. No. 13/217,181, filed Aug. 24, 2011, from all of which priority is claimed and which are all herein incorporated by reference.

BACKGROUND

The present invention relates to data storage systems, and more particularly, to mobile robots for use in tape libraries.

In magnetic storage systems, data are read from, and written onto, a magnetic recording medium utilizing magnetic transducers. Data are written on the magnetic recording medium by moving a magnetic recording transducer to a position over the medium where the data are to be stored. The magnetic recording transducer then generates a magnetic field, which encodes the data into the magnetic medium. Data are read from the medium by similarly positioning the magnetic read transducer and then sensing the magnetic field of the magnetic medium. Read and write operations may be independently synchronized with the movement of the medium to ensure that the data can be read from, and written to, the desired location on the medium.

In a tape drive system, magnetic tape is moved over the surface of the tape head at high speed. Usually the tape head is designed to minimize the spacing between the head and the tape. The spacing between the magnetic head and the magnetic tape is crucial so that the recording gaps of the transducers, which are the source of the magnetic recording flux, are in near contact with the tape to effect writing sharp transitions. Also when the read element is in near contact with the tape, effective coupling of the magnetic field from the tape to the read element is possible.

In the near future, with the adoption of improved media, the cost of storing information (on a per byte basis) on tape is expected to decline by a factor of five or more with respect to magnetic disk. Also, short-term and long-term reliability will continue to favor tape-based storage. Furthermore, as more mass storage is allocated to cloud networks, most storage will be in large libraries, rather than on individual drives, which is a consideration favoring tape-based storage. One disadvantage of tape-based storage with respect to disk-based storage is the relatively poor access time associated with tape-based storage, with the time required to bring the tape to the tape drive and then spool the tape to the file location typically averaging about 40 seconds. If the access time could be reduced, tape-based storage would be better positioned versus disk-based storage for storing files around 10 MB and greater, such as photographs, videos, collections, etc., which are accessed only rarely, but which users want to be able to retrieve almost immediately, e.g., within about a second.

BRIEF SUMMARY

A method according to one embodiment includes causing, using a controller, a mobile robot having a volume of less than about 1000 cubic inches to selectively retrieve one or more of a plurality of tape reels, and causing the mobile robot to transport the one or more retrieved tape reels to a tape drive that is configured for reading data from tape stored on at least

one of the plurality of tape reels. The mobile robot threads a tape on the one or more reels onto the tape drive.

A method according to another embodiment includes causing, using a controller, a mobile robot to selectively retrieve at least one of a plurality of tape reels, causing the mobile robot to transport the at least one retrieved tape reel to a reel chuck, and threading a tape on the at least one retrieved tape reel across a tape drive by moving at least one of the tape reel and a take up reel coupled to the tape.

A method according to yet another embodiment includes causing, using a controller, a mobile robot to selectively retrieve a pair of tape reels coupled to a tape, causing the mobile robot to transport the at least tape reels to a pair of reel chucks, and threading the tape across a tape drive using at least one of rollers and cylinders.

Other aspects and embodiments of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a schematic diagram of a simplified tape drive system according to one embodiment.

FIG. 2 illustrates a system using mobile robots for faster access to tape, according to one embodiment.

FIG. 3 shows a more detailed view of a mobile robot, according to one embodiment.

FIG. 4A illustrates an optical pattern on a surface, according to one embodiment.

FIG. 4B illustrates a surface design, according to one embodiment.

FIG. 4C illustrates a surface design, according to one embodiment.

FIG. 4D illustrates a surface design, according to one embodiment.

FIGS. 5A-5B show detailed views of a mobile robot, according to one embodiment.

FIGS. 6A-6B show detailed views of a tape library using mobile robots, according to one embodiment.

FIGS. 7A-7D illustrate tape threading using a mobile robot, according to one embodiment.

FIGS. 8A-8D show steps of self tape threading using a tape drive, according to one embodiment.

FIGS. 9A-9C show steps of using flange extenders, according to one embodiment.

DETAILED DESCRIPTION

The following description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations.

Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

It must also be noted that, as used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless otherwise specified.

The following description discloses several preferred embodiments of magnetic storage systems, as well as operation and/or component parts thereof.

In one general embodiment, a system includes a plurality of tape reels, a tape drive configured for reading data from tape stored on at least one of the plurality of tape reels, a mobile robot having a volume of less than about 1000 cubic inches, the robot configured for selectively retrieving one or more of the plurality of tape reels and transporting the one or more retrieved tape reels to the tape drive, wherein the robot moves unconstrained along a first surface, and a controller for directing movement of the robot.

In another general embodiment, a system includes a plurality of tape reels positioned on a lower surface, a tape drive for reading data from a tape on one of the plurality of tape reels, at least one mobile robot configured for selectively retrieving at least one of the plurality of tape reels and transporting the at least one retrieved tape reel to the tape drive, wherein the at least one mobile robot moves unconstrained along an upper surface that overlies the plurality of tape reels, and a controller for directing movement of the at least one mobile robot.

FIG. **1** illustrates a simplified tape drive **100** of a tape-based data storage system, which may be employed in the context of the present invention. While one specific implementation of a tape drive is shown in FIG. **1**, it should be noted that embodiments described herein may be implemented in the context of a variety of tape drive systems.

As shown, a tape supply cartridge **120** and a take-up reel **121** are provided to support a tape **122**. One or more of the reels may form part of a removable cartridge and are not necessarily part of the system **100**. The tape drive, such as that illustrated in FIG. **1**, may further include drive motor(s) to drive the tape supply cartridge **120** and the take-up reel **121** to move the tape **122** over a tape head **126** of any type. Such head may include an array of readers, writers, or both.

Guides **125** guide the tape **122** across the tape head **126**. Such tape head **126** is in turn coupled to a controller assembly **128** via a cable **130**. The controller **128** typically controls head functions such as servo following, writing, reading, etc. The controller may operate under logic known in the art, as well as any logic disclosed herein. The cable **130** may include read/write circuits to transmit data to the head **126** to be recorded on the tape **122** and to receive data read by the head **126** from the tape **122**. An actuator **132** controls the position of the head **126** relative to the tape **122**.

An interface **134** may also be provided for communication between the tape drive and a host (integral or external) to send and receive the data and for controlling the operation of the tape drive and communicating the status of the tape drive to the host, all as will be understood by those of skill in the art.

As shown by the partial top down view of FIG. **2** and the cross-sectional view of FIG. **3**, a system **200**, such as a tape library, may include one or more mobile robots **210** for transporting at least one tape reel **202**, which may or may not be part of a tape cartridge, to and from tape drives **204** for reading data from the tape. The tape on the selected tape reel or pair of tape reels may be accessed by the mobile robots **210**, which may be miniature remote-controlled vehicles that move on a surface (such as an upper surface **302**, used interchangeably with the term "ceiling," as shown in FIG. **3**). Thus, the tape reels may lie on a lower surface, such as a "floor," while a mobile robot maneuvers on the upper surface unconstrained, e.g., without the use of rails, tracks, pathways, etc., such as through magnetic attraction between the robot and the upper surface or portions of the upper surface (see FIG. **3**). In one approach, the tape library may comprise more than one level. On each level, tape reels may be arranged on a lower surface (used interchangeably with the term "floor") in a dense pat-

tern. This arrangement is shown in partial top down view of FIG. **2**, according to one embodiment.

A contiguous tape may be stored on a single reel, and may include a pin or other end piece that enables threading of the tape in the tape drive. In other approaches, the tape may be coupled to a pair of reels, e.g., in a tape cartridge.

According to one embodiment, magnetic tape may be included in miniature tape reels **202** which have only a fraction of the tape length of a standard tape cartridge, thereby decreasing seek time. Such shorter length may be, e.g., less than about ⅕th the tape length of a standard Linear Tape Open (LTO) tape cartridge, less than about ⅕₅th the tape length of a standard tape cartridge, less than about ⅕₀th the tape length of a standard tape cartridge, etc. In some approaches, a length of tape on the plurality of tape reels **202** may be less than about 50 meters for each tape reel **202**, and may be preferably less than about 25 meters, more preferably 20 meters or less, etc.

The seek time of tape-based systems using such tape reels may also or alternatively be decreased by increasing the locate speed, e.g., to about 20 meters per second (m/s) or faster. "Locate time" refers to the time required for the tape to wind to the beginning of a data set (or file) after the tape is loaded in the tape drive. If the tape length is reduced to about 20 m or less and the locate speed is about 20 m/s, the average locate time is (20 m/20 m/s)/2=0.5 s. In addition to decreasing the seek time in the drive, the system seek time may be reduced by structuring the tape library to achieve a mean load time of about 0.5 s. "Load time" refers to the time between the first time when a request reaches the tape library and a second time when the relevant tape reel(s) are loaded in the tape drive.

According to one embodiment, the tape system is configured such that the average seek time is less than about 2 seconds, preferably about 1 second or less. The seek time is the delay between a first time when a request to access data is received by the tape library, and a second time when the tape library begins to provide the data to the requester.

With continued reference to FIG. **2**, the tape reels **202** may be closely packed, for example in a hexagonal array, ordered array, circular arrangement, etc., to maximize the number of tape reels that may be stored in a limited amount of space.

According to one embodiment, a diameter of each of the plurality of tape reels **202** may be less than about 100 mm, such as less than about 50 mm, less than about 40 mm, less than about 30 mm.

In some approaches, a single tape drive **204** is available for reading and/or writing tape on the tape reels **202**. Depending on the frequency with which files are read, a plurality of tape drives **204** may be available for reading and/or writing tape on the tape reels **202**, as shown in FIG. **2** by the leftmost tape drive **204** reading a tape. The tape drives **204** may be located about the surface in any arrangement as would be known to one of skill in the art, preferably such that quick access to the tape drives **204** is possible to reduce loading and data access times.

In one approach, the system **200** may be configured to permit the mobile robot **210** to locate, retrieve, and transport any one selected tape reel **202** to the tape drive **204**, and to initialize reading of the tape by the tape drive **204** within about five seconds of receiving a request to read data from the tape of the selected tape reel **202**, more preferably within about 2 seconds, and ideally less than about 1 second.

In several embodiments, several mobile robots **210** move unconstrained along the surface, e.g., two, five, or more. In other embodiments, only a single robot may be present on a given level. It may be advantageous for the robots **210** to be

unconnected by cables to any other part of the system **200**. This design favors fast robot motion, and facilitates the robots **210** being capable of moving between levels, rooms, enclosures, etc. Also, when multiple robots **210** are used, any problem with cables getting tangled together from different robots **210** is eliminated when the robots **210** are controlled wirelessly.

The mobile robots **210** may have predetermined "resting" locations, as shown by mobile robots **210**, according to one embodiment. As shown in FIG. **2**, mobile robot **211** has moved from a resting location, acquired tape reels, and is moving toward a tape drive to load the tape reels in the tape drive for reading tape therefrom. Also, mobile robot **208** has retrieved tape reels from a tape drive which has completed a reading operation, and is returning the tape reels to their storage location. Of course, this movement is exemplary only, and not meant to be limiting on the invention in any way.

The mobile robots **210** may move in straight line increments, or may move more naturally in arcing patterns between positions on the surface, according to various embodiments. Also, the mobile robots **210** may avoid objects in their path according to any method as would be understood by one of skill in the art upon reading the present descriptions.

In some previous tape library geometries, a library gripper accesses an array of tape reels and/or tape cartridges, through motion of a first carriage along a rail or pair of rails. The first carriage in turn holds another set of rails or guides which enables motion of a second carriage holding the gripper. The scheme enables the gripper to access anywhere in two dimensions, where the tape reels or tape cartridges are located. Alternately, in some previous designs, the second carriage has been replaced by a rotary motion which operates about the axes of the first carriage. This scheme limits the flexibility of the library, because grippers (or robots) may interfere with one another. For example, if the grippers use the same set of rails, then they cannot move past each other. Also, there is generally no available space in tape libraries for the installation of an additional set of rails, so this scheme is severely limited in its functionality. In addition, these previous designs do not facilitate easy recovery of access to the tape reels and/or tape cartridges when a gripper fails.

On the other hand, the systems herein use "unconstrained" robots, which facilitate access to the tape reels and/or tape cartridges. Here, the term "unconstrained" indicates that movement is not constrained to rails, tracks, guideways, pathways, etc., but instead movement is free in at least two dimensions, e.g., along a surface. Thus, unconstrained mobile robots are easily added or removed from the surface, and they can easily maneuver around each other along the surface, since they are not fixed to a rail or track.

As shown in FIG. **3**, according to one embodiment, the surface across which the mobile robots **210** travel unconstrained may be an upper surface **302** (such as a ceiling in one approach) and may be unpatterned so that the mobile robots **210** are unconstrained, e.g., not limited to motion on particular tracks, paths, rails, etc. Thus each mobile robot **210** is capable of movement independent of movement of any other mobile robot **210**, e.g., each mobile robot **210** may cross the path that any other mobile robot **210** has taken or will take. Similarly, by attaching the mobile robot **210** to a surface **302** separate from a surface **304** supporting the tape reels **202**, the mobile robots **210** are not constrained to follow aisles, paths, corridors, etc., between groups, columns, rows, etc., of tape reels **202**. In one example, this movement may be analogous to the movement of a shopping cart through a supermarket. However, instead of being constrained to moving between the shelves of the supermarket, the mobile robots **210** are capable

of moving unconstrained along the ceiling of the supermarket, capable of selecting any desired item from below in the shelves, as an example. The ability to use multiple mobile robots **210** to access a group of tape reels **202** provides faster access of short, popular files. This geometry is much more flexible than previous configurations, in which the tape cartridge grippers were supported on x and y positioners which could not cross paths. The mobile robots **210** may be coupled to the upper surface **302** using magnets **310** or some other coupling or attraction device that biases the mobile robots **210** towards the upper surface **302**. By allowing the mobile robots **210** to maneuver on the upper surface **302**, the tape reels **202** may simply rest on a lower surface **304**, such as a floor. The magnets **310** may bias the mobile robot **210** toward the upper surface **302** with much more force than gravity biases the mobile robot **210** toward the lower surface **304**, allowing a much higher frictional force of the mobile robot wheels **306**, **308**, thereby enabling faster robot acceleration and thus faster seek times.

In one approach, the mobile robot **210** may have three wheels **306**, **308**: two rear wheels **308** and one front (maneuvering) wheel or ball **306**. In another three-wheel configuration, the mobile robot **210** may have two front wheels **308**, and a rear (maneuvering) wheel or ball **306**. For sake of clarity, a maneuvering wheel in this discussion indicates a wheel whose direction of positioning or rotation with respect to the robot body is not fixed. Of course, the mobile robot **210** may have any number of wheels **306**, **308** or other apparatus for causing movement of the mobile robot **210** as would be known to one of skill in the art. Steering of the robot may be accomplished in any known manner, such as by independently driving two of the wheels with a caster maneuvering wheel, steering using the maneuvering wheel, and driving and steering with the maneuvering wheel, etc.

The mobile robot **210** may have a reel gripper **312**, which when the mobile robot **210** is positioned above a desired tape reel **202** or set of tape reels **202**, may grab, attract (for example, magnetically), secure, or otherwise take hold of the tape reel **202** such that it may be loaded into the mobile robot **210** and transported to a tape drive or back from a tape drive to the tape reel's storage location.

With continued reference to FIG. **3**, in some embodiments, the mobile robot **210** may have a height such that it may be able to maneuver above the tape reels **202** in a space H of about 1.75", which measures about 1 U in a standard rack configuration. The smallest units used for rack-mounted computer components are "1 U" units, which are 1.75" high. Since a reel for standard 0.5" wide magnetic tape may be as thin as 0.58", this 1 U unit may be thick enough to hold a single layer of storage having a layer of tape reels **202** plus mobile robots **210**. Thus a single layer design having mobile robots **210**, tapes **202**, and drives may be used for various tape library configurations, ranging from a single layer to multiple stacked layers, which may fill an entire storage room, or any size desired.

In one approach, the plurality of tape reels **202** may be spaced from and located within a distance of about 15 cm from the upper surface, e.g., 15±1.5 cm, less than about 20 cm, less than about 10 cm, less than about 5 cm, or any value in the foregoing ranges.

The system **200** may also comprise a controller **212** for directing movement of the robot **210**. The controller **212** may be on board the robot **210**, or away from the robot **210** (as shown in FIG. **2**) and in communication therewith via any type of communication channel (such as wireless, wired, infrared, etc.).

According to one illustrative embodiment, a system **200** comprises at least one tape drive **204** configured for reading data from tape stored on one of a plurality of tape reels **202**, at least one mobile robot **210** having a volume of less than about 1000 cubic inches (and in some approaches less than about 900 in³, less than about 750 in³, less than about 500 in³, less than about 250 in³, less than about 100 in³, less than about 50 in³) configured for selectively retrieving one or more of the plurality of tape reels **202** and transporting the one or more retrieved tape reels **202** to the tape drive **204**. The mobile robot **210** moves along a surface, and is preferably not mechanically constrained to move along a pre-determined trackway or path (i.e., it is unconstrained). In some approaches, the robot **210** may be mechanically unconstrained and may be able to move autonomously across the surface via any desired path.

To assist in navigation of the mobile robot **210**, at least one of the lower and upper surfaces may include an optical pattern usable for navigation of the mobile robot **210**, and the mobile robot **210** may be configured for recognizing the optical pattern.

As shown in FIG. **4A**, the lower surface or floor **304**, for example, may include an optical pattern **402** designed for the mobile robot to locate its position. This optical pattern **402** may be a rectangular grid extending over the entire floor **304**, with each grid square **404** labeled with readable code identifying the row and column of the particular grid square **404**. This readable code may take any form as would be understood by one of skill in the art.

The floor **304** may be planar, as shown in FIG. **4B**, covered with small indentations as shown in FIG. **4C**, or have a lattice defining receptacle areas in which the tape reels **202** are positioned as shown in FIG. **4D**, according to various embodiments. By extending the lattice up past the tape reels **202**, it may form a surface on which the mobile robot **210** may be supported, and the mobile robots **210** would not maneuver along the upper surface but instead would maneuver on the lower surface formed by the top surface of the lattice, according to one embodiment.

The design of the mobile robot **210** may include additional features, abilities, etc., as would be understood by one of skill in the art upon reading the present descriptions. In one embodiment, a mobile robot **210** is shown in FIGS. **5A-5B**, according to one approach. In this example, one or more motors **508** power symmetric drives wheels **308** that allow forward and backward motion, and in a further approach, the drive wheels **308** may provide steering if the drive wheels **308** are operated independently using two symmetric drive motors **508**. These motors **508** may be attached to each wheel **308** by a single step-down gear. The mobile robot **210** may additionally be supported by one or more other omni-directional passive wheels **306**, which may move in any direction, and may be maneuverable (e.g., steerable, positionable, etc.), in some approaches. The omni-directional wheel(s) **306** may be caster wheels, and more preferably may be spherical balls which are also referred to as ball transfers.

To pick up the tape reel(s) **202**, a simple platform **312** may be lowered and raised by a solenoid or motor (not shown). If the tape reels **202** are topped by a magnetic plate, the tape reels **202** may be gripped to the platform **312** by energizing electromagnets **502**. One or more cameras **504** may allow for navigation of the mobile robot **210**. A camera **504** may be placed above each reel holding position **506**, enabling the mobile robot **210** to determine its position and to deliver a tape reel **202** directly into a tape drive. The mobile robot **210** need not be made precisely, because the cameras **504** may simultaneously image the tape reels **202** and location grid (or

the tape reel chucks on the drive) to precisely position the tape reels **202**, in some approaches.

To enable multiple mobile robots **210** to work in the same work space, such as the same floor, there are preferably no cables attached to the mobile robots **210**. The mobile robot **210** uses little power, and a peak speed of about 2 m/s in some embodiments is sufficient to pick up the tape reel **202** and bring it to the drive within a half second. For a 150 gram mobile robot **210**, the corresponding kinetic energy would be about 0.3 Joule. This amount of energy may be supplied by a rechargeable battery, through inductive coupling, etc., but a capacitor, with its extremely long lifetime, may be preferable. In one embodiment, an 80 volt, 1000 μF electrolytic capacitor which includes 3.2 Joules, yet is only 16 mm diameter by 40 mm long may be used. The mobile robot **210** may be recharged at its parking position, or at the tape drive when it loads the tape reel **202**.

As shown in FIG. **5B**, according to a preferred embodiment, the tape reels **202** are positioned on a floor **304**, the surface **302** is opposite the floor **304**, and the mobile robot **210** is biased toward the surface **302**, such as through magnetic biasing (by using magnets **310**), thereby suspending the robot **210** above the tape reels **202**. For example, the mobile robot **210** may be magnetically biased toward the upper surface **302**.

As shown in FIGS. **6A-6B**, a library controller may communicate with the mobile robots **210** by light, such as infrared (IR); radio frequency (RF); etc., and may be differentiated on each level of the library **200** to avoid cross-talk. The library controller computes a path the mobile robot **210** is to take to pick up and drop off the tape reels and load the tape reels in the tape drives **204**. The mobile robot **210** may servo along the path by using its cameras, in one approach, or it may use encoders on its motors or wheels to servo, using the cameras only for fine adjustments, in another embodiment.

In one embodiment, the tape library **200** may comprise a plurality of tape drives **204**, where each tape drive **204** is positioned on the floor supporting the tape reels, the floor being below the surface on which the mobile robots **210** maneuver by a distance sufficient to allow movement of the mobile robots **210** therebetween (between the tape reels and the surface).

In large multilayer libraries **200**, mobile robots **210** may move between floors using ramps **604**. This enables the mobile robots **210** themselves to load different floors with tape reels, and to rebalance the work load by optimally locating the mobile robots **210** and organizing the tape reels. The relative number of mobile robots **210**, tape reels, and tape drives **204** may be determined by the access frequency of the files, data, etc.

According to one approach, multiple surfaces having a spaced and stacked configuration may be used, and the mobile robot **210** is configured to travel between the multiple surfaces. In this approach, at least one ramp **604** may be provided, connecting at least two of the multiple surfaces, thereby permitting the mobile robot **210** to travel between the multiple surfaces. In these or any other approaches, there may be no cable coupled between the mobile robot **210** and any other component of the system.

As illustrated in FIG. **6B**, according to one embodiment, one or more tape drives **204** may be secured directly to the floors **606** of a tape library **200** having one or more levels. In addition, the mobile robots **210** may be attracted to the ceilings **602**. In this design, the drive(s) **204** may be easily positioned at any location in the tape library **200** by simply leaving space in the array of reels (not shown). This arrangement facilitates reconfiguration of the tape library **200** after it has

been manufactured, along with replacement of failed tape drives should they occur. For example, the mobile robots **210** may be adapted for moving and/or relocating a tape drive **204**. At least one tape drive **204** may be positioned on each level of the tape library **200**, according to one embodiment.

The library can be configured to have "spare" tape drives **204** and mobile robots **210** ready to be put into use upon failure of other tape drives and mobile robots, according to one embodiment. In another embodiment, when extra tape drives **204** or mobile robots **210** are to be used, due to some factor, such as an increased work load, failed mobile robots and/or tape drives, etc., the tape library **200** may allow adding or removing tape drives, tape reels, and/or mobile robots by the user after manufacture of the tape library **200**.

Any type of tape threading system known in the art may be adapted for use with the systems described herein, according to various embodiments. For example, if tape reels are used individually (not as pairs), a standard threader mechanism may be used to thread the tape reel onto the tape drive, according to one embodiment. Storing the tape on pairs of reels has an advantage in that after loading, the tape is ready to be used and does not need to be wound onto another inboard reel. Also, when the tape is finished being used, both reels may be removed with the tape, and the tape does not need to be unwound from the inboard reel in order to be removed.

In another embodiment, as shown in FIG. 7A, the tape drive **204** itself may have no threader. Rather, the mobile robot **210** may be configured to thread tape **706** of the retrieved tape reel **702** onto the tape drive **204**. In one approach, a mobile robot **210** loads the tape **706** provided on a pair of tape reels **704, 704,** by first dropping off one reel **702** on the drive **204,** and then the other reel **704** on a reel chuck **708,** for which a reel motor may wind the tape **706**. Alternately, if the tape **706** is stored on one reel only (such as reel **702**), the mobile robot **210** may move an end of the tape not on the reel **702** to secure it to the inboard drive wheel, as described in relation to FIGS. 7B-7D. The precision of the mobile robot **210** motion may be much greater than that of a leader pin loader mechanism currently used in tape drives, in some approaches.

In another embodiment, as shown in FIGS. 7B-7D, a single reel **702** of tape **706** may be loaded onto a reel chuck and motor **714** which are fixed to a carriage **716** that is adapted to follow a guide **718** that allows for motion of the chuck **714** around the tape drive **204** to facilitate threading of the tape **706**. Before loading the reel **702** on the chuck **714,** the chuck **714** is brought into proximity of the inboard (take-up) reel **710,** as shown in FIG. 7B. After the mobile robot (not shown for clarity) places the reel **702** on the chuck **714,** a mechanism **712** attaches the end of the tape **706** to the take-up reel **710**. See FIG. 7C. At this point, the tape **706** may be transferred between reels **702** and **710** as part of a preliminary locate operation, before the tape **706** contacts the recording head **720** or any guide surfaces, such as rollers, thus enabling faster tape locate with reduced tape damage and drive wear. Then, the chuck and reel motor **714** and tape reel **702** are moved along the guide **718** to a final position, as shown in FIG. 7D, where the tape **706** may be read from or written to.

In another embodiment, rather than moving the library reel **702** and carriage **716,** the take-up reel **710** and its motor may be moved to thread the drive **204.** In yet another embodiment, if the tape **706** is stored on a pair of reels, the mobile robot may position the two reels directly on the tape drive **204,** where the tape **706** may be located before threading.

Alternatively, as shown in FIGS. 8A-8D, the tape **706** may be held on two tape reels **202,** and a method may be used

which avoids the unreliability of a leader pin. In this approach, the reel drive chucks **802** may be spaced with the same close spacing of the tape reels **202** in their storage position. The mobile robot places the tape reels **202** on the chucks **802,** as shown in FIG. 8B, and two moveable rollers **804, 806** sequentially thread the tape **706** in position. First, roller **804** threads the tape **706,** as shown in FIG. 8C, and then roller **806** threads the tape **706,** as shown in FIG. 8D. The tape **706** may locate before the rollers **804, 806** move into their final position, thus avoiding the extra wear and control difficulties associated with contact of the tape **706** with the roller **806** or other guide surfaces and the head. Alternately, two smooth cylinders which form air bearings may be used to thread the tape drive, in another embodiment.

In one embodiment, each reel may be large enough (e.g., the flanges are big enough) to hold the entire length of tape, if all the tape is to be accessed. If the tape is stored in pairs of these large reels, the capacity of the library may be reduced by a factor of two from what it may be by using single reels.

In another approach, the tape may be stored on a pair of reels, where at least one reel is not large enough to accept the entire length of tape. As shown in FIGS. 9A-9C, a reel-size reduction may be effected by incorporating temporary flange extenders **902, 904** in the tape drive. In the tape drive, a temporary flange extender **902** is fixed to the motor/reel chuck **908** so that the reel flange **906** is extended when it is on the drive. Once the reels **202** are in the drive, another flange extender **904** is placed on the top of each of the reels **202,** so that tape can be spooled onto one of the reels. Before the tape reels **202** are unloaded from the tape drive, the tape is spooled back evenly between the tape reels **202,** so that it lies only between the permanent flanges **906** on the tape reels **202**.

In another approach, a packing roller may be used to keep the tape on the reel after its diameter becomes bigger than the flange.

In some approaches, the tape library may be fault tolerant and/or self repairing. For example, each tape cartridge may be read by a number of different drives, if a robot fails then other robots may maneuver around the failed robot, a failed robot may be towed away by another robot and replaced, and/or a failed tape drive may be towed away and replaced.

According to one embodiment, if a mobile robot fails, it may be towed away and replaced by another mobile robot. The tape drives may be configured so that a mobile robot may easily tow away and replace a tape drive, after temporarily clearing away the tape reels that may be in the path taken to remove the tape drive. The power and data connections may be made to use very little force, for example, using simple sliding spring contacts for the power and optical link for the tape drive data transfer.

According to one embodiment, the system may be configured to allow removal of a failed mobile robot using another mobile robot, in which case the failed mobile robot may then be replaced with the mobile robot performing the removing or another mobile robot, in some approaches.

In another embodiment, the mobile robot may be configured to remove the tape drive, e.g., if the tape drive is broken. Likewise, the robot may install a replacement or repaired tape drive.

It will be clear that the various features of the methodologies and embodiments described herein may be combined in any way, creating a plurality of combinations from the descriptions presented herein.

Communications components such as input/output or I/O devices (including but not limited to keyboards, displays, pointing devices, etc.) may be coupled to the system either directly or through intervening I/O controllers.

Communications components such as buses, interfaces, network adapters, etc., may also be coupled to the system to enable the data processing system, e.g., host, to become coupled to other data processing systems, remote printers, storage devices, etc., through intervening private or public networks. Modems, cable modems, and Ethernet cards are just a few of the currently available types of network adapters that maybe used, in some approaches.

It will be further appreciated that embodiments described herein may be provided in the form of a service deployed on behalf of a customer to offer service on demand.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of an embodiment of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A method, comprising:
causing, using a controller, a mobile robot having a volume of less than about 1000 cubic inches to selectively retrieve at least one of a plurality of tape reels; and
causing the mobile robot to transport the retrieved tape reel to a tape drive that is configured for reading data from tape stored on at least one of the plurality of tape reels,
wherein the retrieved tape reel is a single reel of tape, wherein the mobile robot threads the tape on the retrieved reel tape reel onto the tape drive by moving an end of the tape not on the reel to an inboard drive wheel.

2. A method as recited in claim 1, wherein the mobile robot moves unconstrained along a first surface.

3. A method as recited in claim 1, wherein the tape reels are positioned on a second surface, wherein a first surface is opposite the second surface, the mobile robot being biased toward the first surface.

4. A method as recited in claim 1, wherein each tape reel has a length of tape thereon of less than about 50 meters.

5. A method, comprising:
causing, using a controller, a mobile robot to selectively retrieve at least one of a plurality of tape reels;
causing the mobile robot to transport the at least one retrieved tape reel to a reel chuck; and
threading a tape on the at least one retrieved tape reel across a tape drive by moving at least one of the tape reel and a take up reel coupled to the tape.

6. A method as recited in claim 5, wherein the mobile robot has a volume of less than about 1000 cubic inches.

7. A method as recited in claim 5, wherein the mobile robot moves unconstrained along a first surface.

8. A method as recited in claim 5, further comprising performing a preliminary locate operation by transferring the tape between the reels before the tape contacts a recording head and/or a guide surface of the tape drive.

9. A method as recited in claim 5, wherein the tape reel is moved along a guide to thread the tape onto the tape drive.

10. A method as recited in claim 5, wherein the take up reel is moved along a guide to thread the tape onto the tape drive.

11. A method as recited in claim 5, wherein the tape is stored on the tape reel and take up reel, wherein the mobile robot retrieves the reels and positions the reels on the tape drive.

12. A method as recited in claim 5, wherein the tape reels are positioned on a second surface, wherein a first surface is opposite the second surface, the mobile robot being biased toward the first surface.

13. A method as recited in claim 11, further comprising performing a preliminary locate operation by transferring the tape between the reels before the tape contacts a recording head and/or a guide surface of the tape drive.

14. A method, comprising:
causing, using a controller, a mobile robot to selectively retrieve a pair of tape reels coupled to a tape;
causing the mobile robot to transport the tape reels to a pair of reel chucks; and
threading the tape across a tape drive using at least one of rollers and cylinders.

15. A method as recited in claim 14, further comprising performing a preliminary locate operation by transferring the tape between the reels before the tape contacts a recording head and/or a guide surface of the tape drive.

16. A method as recited in claim 14, wherein the mobile robot has a volume of less than about 1000 cubic inches.

17. A method as recited in claim 14, wherein the mobile robot moves unconstrained along a first surface.

18. A method as recited in claim 14, wherein the tape reels are positioned on a second surface, wherein a first surface is opposite the second surface, the mobile robot being biased toward the first surface.

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